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A Field Study of Longwall Mine Ventilation Using Tracer Gas in a Trona Mine

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Abstract

A ventilation research study was conducted by the National Institute for Occupational Safety and Health and a cooperating trona mine in the Green River basin of Wyoming, USA. The mine operation uses the longwall mining method in trona bed 17, a commonly mined unit in the region. The longwall face length is 228 m (750 ft), and caving on the face occurred up to the back of the longwall shields. The mine is ventilated using a main blowing fan and a bleeder shaft. For this study, sulfur hexafluoride (SF_6) tracer gas was released in two separate monitoring experiments. For the first experiment, tracer gas was released on the face, this test focused on airflow along the longwall face of the active panel. Face test showed the airflow patterns to be more complex than just head-to-tail flow in the main ventilation air stream on the active panel. For the second experiment, tracer gas was released 2 crosscuts inby the face on the headgate side, this test focused on gas transport in the mined-out portion of the same active panel. Gob test showed a pathway of movement through the front of the active panel gob that moved outby from the tailgate corner. The primary pathway of tracer gas movement in the active panel gob was towards the headgate and tailgate bleeders and out of a bleeder shaft. The rate of movement towards the back of the gob was measured to be 0.19 m/s (37 fpm).

Keywords

Mine ventilation; Longwall mining; Trona; Tracer gas

1 Background

1.1 Overview

In longwall mining, ventilation is considered one of the more effective means for controlling gases and dust. Sufficient ventilation air on a longwall face is critical for safety and health of crews working in the face area and to meet statutory requirements for gas and dust

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Conflict of Interest The authors declare that they have no conflict of interest.

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concentrations. In addition, air flow into the void behind the shields and into the gob may be considered beneficial for diluting the gases and rendering them harmless, However, such air diversions and losses can remove ventilation airflow from the face, thus reducing effectiveness to control both dust and gases. In addition, average longwall face lengths have increased significantly in the last 10 years, a trend that shows no sign of abating [1]. Increasing face length increases the resistance to face ventilation flow and increases the tendency for this airflow to find flow paths of lower resistance elsewhere. These paths may be located inby the shield line, resulting in lower face airflow and reduced capability to dilute methane. Longwall face lengths currently range from 200 to 300 m (650 to 1000 ft) for operations under deep cover in Colorado, Utah, and Wyoming. Longwall mines in the Illinois (Herrin No. 6) and Northern Appalachian Basins (Pittsburgh No. 8) have longer face lengths starting at 300 m (1000 ft) and increasing up to 480 m (1580 ft) under low to moderate depth of cover. Central Appalachian Basin's longwall length ranges from 210 to 300 m (700 to 1000 ft) due to depth and coal seam conditions [1]. Caving characteristics vary from the tightly compacted gobs found in the Central Appalachian and San Juan Basins to the gobs that are much less dense as found in the Illinois Basin. Due to such variations in face length and caving characteristics, the severity of airflow exchanges between face and gob is likely to exhibit considerable variation.

National Institute for Occupational Safety and Health (NIOSH) ventilation researchers sought to identify flow paths of ventilation airflow on longwall panels with variations in roof caving characteristics and longwall face lengths. To achieve this goal, three field sites were chosen of varying face lengths and caving characteristics; 228-m (750 ft) face length with bleeder ventilation (bleeder shaft) and caving up to the shields (this study), 305-m (1000 ft) face length with bleederless ventilation and caving up to the shields [2], and 381-m (1250 ft) face length and bridging void space behind longwall shields [3, 4]. In addition to the field studies, the research team also investigated the important aspects of longwall ventilation using numerical modeling and scaled physical modeling. Numerical modeling research utilized computational fluid dynamics modeling and discrete fracture network modeling concept [5]. Physical modeling research was conducted on a 1:30 scale physical model called "Longwall Instrumented Aerodynamic Model (LIAM)" [6–8]. The findings described in this paper contribute towards the overall assessment of ventilation of longwall mines.

The objective of this research was to develop an understanding of the role of gas dynamics in variable broken rock and investigate airflow exchanges between the face and gob. This paper reports on results from a field study using tracer gas to describe face air and gob area gas movements in a longwall panel at a trona mine ventilated with a bleeder ventilation system. The study was conducted on an active panel and included both underground and surface monitoring sites. The study used sulfur hexafluoride (SF_6) tracer gas released as a slug on the longwall face and in the front of the gob inby the face. Tracer gas technique has been widely used by researchers around the world to successfully investigate the mine ventilation systems. Some of the original methods and applications of tracer gas in underground mines were developed at the Bureau of Mines and NIOSH [9–12]. Schatzel et al. and Krog et al. used SF_6 to study methane emissions, bleeder performance, and airflow patterns on longwall faces [13, 14]. Pandey et al. and Singh et al. investigated the air leakage rates through ventilation stoppings using SF_6 [15,16]. Jong et al., Watkins et al., and Xu et

al. utilized perfluoromethylcyclohexane (PMCH) to investigate mine ventilation systems [17–19].

1.2 Resource

Trona is classified as sodium sesquicarbonate and has the chemical formula $Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$. US trona deposits of economic value are found in the western portion of the state of Wyoming (Fig. 1). There are as many as 40 separate beds in Sweetwater County, WY, of potential economic value. These trona deposits in southwestern Wyoming are recognized as the greatest source of natural sodium carbonate in the world. In 1995, it was estimated that 22 of the beds present in this region were more than 1.2 m (4 ft) thick at depths of about 198to 914 m (650 to 3000 ft) [21]. There are multiple mines operating in trona bed 17, although mining operations are known to occur in other trona beds in the basin.

The trona beds of Sweetwater Country, WY, are Eocene (Tertiary) in age and are part of the Green River Formation known for abundant oil shale resources. Trona is present in expansive lacustrine deposits which are primarily found in the Wilkins Peak Member of the Green River Formation (Fig. 2) [20].

Mining of these Wyoming trona beds is done by underground methods. Room-and-pillar and longwall mining operations are both present in the Green River Basin. The underground trona mines in the Green River Basin are classified as gassy by the Mine Safety and Health Administration (MSHA), the primary federal mining regulatory agency in the USA. Methane emissions from some mines can exceed 30,000 m^3/day (1,000,000 cfd) due to the presence of organic matter in the Green River Formation oil shales. Trona mines are classified as category “3” in the MSHA regulatory scheme [22]. The mine site for this study employed longwall mining in trona bed 17. Some considerations for ventilating trona mines are discussed by Prichard [23].

1.3 Study Site

The longwall panel for the ventilation study is shown in Fig. 3. The face width is 228 m (750 ft) and panel length is 3010 m (9860 ft). The height of the mined face ranged from about 2.7 to 3.0 m (9 to 10 ft). Overburden depth is approximately 490 m (1600 ft). The mine operator utilizes blowing ventilation throughout the mine.

The longwall face is ventilated by two intake (including the belt entry) and two return airways (Fig. 4). Airflows in the intake airways are roughly 9.4 m^3/s (20,000 cfm) in entry 1 and 33 m^3/s (70,000 cfm) in entry 0. Additional flow and cross-sectional area measurements were made on the longwall face and are given in Table 2.

The mine operator ventilates the mine with a main blowing fan and a bleeder shaft. A bleeder system is used for the longwall mining portion of the mine. The bleeder shaft is located near the study panel and provides a direct pathway to the surface for return airflow on the study panel; the bleeder shaft does not have an exhausting fan.

Caving characteristics in relation to the study are described as normal, meaning the overburden caved up to the back of the shields immediately after the longwall shields advanced. NIOSH has conducted similar face ventilation investigations at coal mines where very strong roof rock units allowed the roof to stand up for a period of time after the face retreated.

1.4 Approach

NIOSH researchers have gained a wealth of relevant field experience at longwall operations with widths varying from 305 to 400m (1000 to 1300 ft) and with tightly and loosely caved gobs. These operations were located in the northern and central Appalachian and western coal basins. Researchers typically gathered operational and geologic data, ventilation and environmental data in accessible areas, and flow rates in inaccessible areas using tracer gas studies. To complement this accumulated database, a trona site with a shorter face length 228 m (750 ft) was chosen for this study. Trona mines are considered to be among the gassier types of metal/non-metal mines, with certain operational characteristics, such as dilution of gob gas, being closest to coal mines. Therefore, the researchers and the mine operator were very interested to investigate longwall ventilation in greater detail at this site.

2 Experimental Methodology

The general concept of gas flow characterization experiments is to release a defined volume of a tracer gas into the ventilation airflow or longwall gob and then monitor all potential exit points for arrival of that gas. The volume of tracer gas passing through each monitoring station can be calculated by determining tracer gas concentrations and measuring the associated gas flow rate. For this study, sulfur hexafluoride (SF_6) tracer gas was released in two separate monitoring experiments. One test was focused on airflow along the longwall face of the active panel, while the second focused on gas transport in the mined-out portion of the same panel (Fig. 3). This approach permitted the volumes of the tracer gas released and the duration of monitoring to be optimized for each test. The methodology for this tracer gas approach has been described in greater detail in previous publications by the US Bureau of Mines and NIOSH [2, 3, 9–12].

2.1 Gas Release

Tracer gas was released from lecture bottles containing roughly 34 L (1.2 ft^3) of high-purity SF_6 at 101.325 kPa and 0 °C. The SF_6 gas was released in a rapid short-term fashion (slug) and its migration through the mine was tracked by sampling at different monitoring stations. For the face test, 0.35 L (0.012 ft^3) SF_6 was released for about 2 s near the mid-height in the leg of the first shield on the headgate side. For the gob test, 92.1 L (3.25 ft^3) SF_6 was released two crosscuts inby the face on the headgate side. The SF_6 release volume for the gob test was much greater than that for the face test to achieve detectable and measurable gas concentrations in the gob void space. These release volumes were determined by calculating released mass and further corrected for underground ambient temperature and pressure conditions, using ideal gas law conversions.

2.2 Gas Sampling

The tracer gas samples were collected in evacuated 15-ml glass vials at each monitoring station by manual sampling of ventilation air drawn through polyethylene tubing. The tubing was 0.95 cm (0.38 in.) ID and 1.3 cm (0.5 in.) OD in size and was attached to permissible SKC, Inc. Aircheck 224-44XRM vacuum pumps. This sampling method has also been reported previously in greater detail [2, 3, 13, 14].

For the face test, the tubing inlets were positioned on the long axis of the centerlines of shields 7, 33, 65, 98, and 124. These inlet positions correspond to face locations of 11.4 m, 57.2 m, 114.3 m, 171.5 m, and 217.2 m (37.5 ft, 187.5 ft, 375 ft, 562.5 ft, and 712.5 ft). There were 131 shields on the face totaling 228.6 m (750 ft) in length. Sampling was also conducted at two additional near-face monitoring locations approximately 24.3 m (80 ft) inby and outby the working face in the tailgate gateroad (Fig. 4). The initial sampling interval was two per minute on each of the face test tubing lines for the first 30 min. Sampling becomes less frequent for the duration of the test to one sample every 10 min for the last 30 min. The overall duration of monitoring for the face test was 4 h.

For the gob test, samples were retrieved at seven locations; headgate inby and outby the face, tailgate inby and outby the face, headgate and tailgate bleeder entry, and bleeder shaft on the surface (Fig. 3). Depending on the monitoring location, the samples were collected more frequently at an interval of every 15 min to less frequently at an interval of every 45 min. The gob test ran for 5 days, one shift per day.

For both the face and gob tests, the sample pumps ran continuously at the max rate of 5.0 L/min (0.18 cfm) during sampling intervals. Using the tubing lengths and pump rates for each monitoring location, the transit times of the gas through the tubes were calculated and corrections were made to the sampling times accordingly. Transit times for the movement of samples through the polyethylene tubing were computed by determining friction factors following testing at NIOSH and during pump tests performed in the field after installation. These tubing transport times were subtracted from the tracer gas arrival times at each sampling site to determine tracer gas movements (Table 1).

2.3 Gas Analysis

Samples collected during the field study were analyzed for SF_6 concentrations by gas chromatography. Samples were drawn from the bottle samples and analyzed using a modification of NIOSH Method 6602 by a Shimadzu GC8 with an electron capture detector [24]. The GC configuration was discussed previously [2, 3, 13, 14]. The limit of quantification for the GC method is about 1 ppb SF_6 in air.

2.4 Field Measurements

The test design for the study included the measurement of several parameters including velocity, airflow, and barometric pressure. Airflows were calculated by measuring face velocities and approximating the cross-sectional areas. Airflow data are given in Table 2.

Air velocity readings were taken at five gas sampling locations on the face in the zero entry and inby and outby the tailgate corner (Fig. 4). The air velocity readings were taken with a

vane anemometer utilizing the traverse method. The cross-sectional area was measured by taking multiple readings of height and width wherever possible. The cross-sectional area for line 6 was approximated by the researchers in the field as the sampling location was inby the face and under unsupported roof.

3 Results and Discussion

3.1 Face Test

The face test was conducted during a daylight non-production shift on the first day of the field study. During the entire duration of this test, the shearer was positioned at the zero entry. The tracer gas (SF_6) was released for about 2 s near the leg of the first shield on the headgate side (Fig. 4). Monitoring was initiated at the time of the release from all face monitoring locations. The released volume of SF_6 was 0.35 L (0.012 ft^3), determined by the released mass and corrected for underground temperature and pressure conditions.

3.1.1 Lines 1 to 3—As shown in Fig. 4, line 1 is located at shield no. 7 near the tracer gas release location. Line 2 is located at shield no. 33 between the zero entry and mid-face, and line 3 is located at shield no. 65 near the mid-face region on the face. Figure 5 shows the data from samples taken on the face for lines 1 to 3. The *x*-axis shows time elapsed since the release of tracer gas. The time of sampling is corrected for the transit time through the tubing lines using the pump velocities and lengths of tubing (Table 1).

The sampling location closest to the release point was line 1; however, tracer gas was not measured here until 23 min after release. Such behavior is thought to be representative of tracer gas residing in the gob for a period of time before flowing back on the face.

On line 2, a detectable amount of tracer gas was not seen throughout the duration of the sampling period. The lack of tracer gas at line 2 may be the result of the influx of fresh air in the zero entry. Line 2 was the first sampling location on the face inby the zero entry. The intake airflow in zero entry was measured at 33.5 m^3/s (71 kcfm), and this air mixed with the existing intake air from headgate entry number 1. Tracer gas movement at line 2 was likely affected by the flow of gas in the zero entry entering the face airflow.

The first measured arrival of tracer gas was seen at line 3, approximately 4 min after the release of gas. The first peak (movement of released slug) also appears first at this location. This behavior of tracer gas suggests that a portion of air from the release location traveled in a region behind the shield line and reached the mid-face region first.

3.1.2 Lines 4 and 5—Tracer gas data from lines 4 and 5 are shown in Fig. 6. Line 4 was located at shield no. 98 and, line 5 was located at shield no. 124 at about 75% and 95%, respectively, of the overall face length towards the tailgate. The tracer gas arrived at lines 4 and 5 at approximately the same time, 4 min after the release. The last occurrence of SF_6 was measured 20 min after release for both the locations. Such behavior of gas indicates transport from the release point to the tailgate end of the face through an undefined pathway. The gas stayed on the face for 20 min at lines 4 and 5 on the tailgate side of the face.

3.1.3 Lines 6 and 7—Data from lines 6 and 7 during the face tracer gas test are shown in Fig. 7. Line 6 was located one break inby the face in the former number 1 tailgate gateroad. Line 7 was located one break outby the face. The tracer gas arrived at line 6 prior to arriving at line 7. The concentrations measured for these arrivals and peaks were higher for line 6 than line 7. On line 6, the peak was recorded 6 min after the time of release. The determined concentrations for line 7 were intermittent and the peak was recorded 54 min after the time of release. At line 7, there were measurements of SF_6 above 1 ppb, until 1.5 h after the release, which may indicate residence time within a portion of the gob. Such behavior demonstrates rapid movement of tracer gas to line 6 and a longer duration of tracer gas at line 7.

3.2 Gob Test

The gob test was conducted for a duration of 5 days. For this test, SF_6 was released two crosscuts inby the face on the head-gate side, at crosscut 20 (Fig. 8). The operator was mining on the evening 8-h shift and NIOSH staff were monitoring during the daylight shift. Only one shift per day was monitored during the study. For this test, the tracer gas release was designed to be much greater than the face release to account for dilution in the gob, so that the anticipated SF6 concentration in the gob void space was at good experimental concentrations for measurement. Recognizing the dilution and slow transport characteristics, gob release is designed to target high initial concentrations (100–350 ppb) at the bleeder sampling locations.

Two lecture bottles of 99.95% SF_6 were released in succession, totaling 92.1 L (3.25 ft^3) at underground ambient conditions. After the release of SF_6 was completed in crosscut 20, 265 L (9.34 ft^3) of compressed CO_2 was injected to clear the sampling port and sample line of SF_6 and mix the tracer in the gob. Sampling commenced at all monitoring locations following the release.

3.2.1 Tailgate Outby—The samples at this monitoring location were collected in tailgate entry #1 at crosscut 16, one break outby the face. Sampling was initiated as soon as the tracer gas was released. Tracer gas arrived at this location 5 min after the release. The recorded concentrations throughout the duration of testing were quite low, on the order of 3 ppb (Fig. 9). Low concentrations of tracer gas at the tailgate outby location show that only a small portion of tracer gas mixture moved along this path. Tracer gas was present on both day 1 and day 2 of testing. A possible explanation for such behavior is that the gas moved outby from the release location towards the face and eventually mixed with face air flowing towards the tailgate. However, the focus of this test was on gob gas transport and potential face air interaction. Without gas sampling on the face during this test, the exact path of near-face movement is not known. The lower concentrations recorded are due to high airflow on the face and tailgate outby. The velocity based on arrival times for this monitoring location is approximately ~0.91 m/s (~ 180 fpm). Caving was observed up to the shields during this testing.

3.2.2 Tailgate Inby—On the tailgate inby side of the face, the samples were collected at crosscut 17 in tailgate entry number 1. During the duration of testing, tracer gas was not

measured at this location. Based on the large quantity of air moving inby on the tailgate side and low concentrations of tracer gas on the outby side, it is highly probable that tracer gas was present at this location but that the concentration was below the detection limit of the gas chromatograph. Prior NIOSH research has shown that airflow at the tailgate corner moves mostly inby in the direction of the bleeders.

3.2.3 Inby and Outby Headgates—The samples were collected in headgate entry number 1 at crosscut 17 on the inby side of the face and crosscut 16 on the outby side. No tracer gas was measured at this location during the duration of the testing. Based on the release location, it was considered unlikely for the gas to be present here since air was moving primarily from the headgate side to the tailgate side or towards the bleeders.

3.2.4 Tailgate Bleeder—The tailgate bleeder sampling was done at the intersection of the back bleeder entries and tailgate entry number 2. The first arrival of tracer gas was recorded after approximately 2.5 h of release time (Fig. 10). Samples were collected at this location every 30 min during the day shift for the entire testing duration of 5 days. Tracer gas concentrations on day 1 of the test were an order of magnitude higher than for the later tests. However, rising concentrations recorded on day 1 followed by lower tracer gas concentrations on day 2 indicate that the peak concentration was not measured. As the sampling was carried out only during the non-production shift, the peak likely occurred during the production shift on day 1. The concentrations on day 1 at this location were lower compared with the concentrations at the headgate bleeder location, as the airflow was higher on the tailgate side. The air at the headgate bleeder sampling location moved towards the tailgate bleeder sampling location, as shown in Fig. 8. At this location, except for the first day, measureable concentrations on the order of 2 ppb were recorded for 4 days of sampling. This indicates that a portion of the gas stayed within the gob, though moving at a slow rate.

3.2.5 Headgate Bleeder—Figure 11 shows the sampling data at the headgate bleeder in the back of the panel. SF_6 arrived at the inby bleeder location on the day of the release. The concentration was 24.6 ppb, which quickly increased to 467.4 ppb in the next 2 h. The last readings of the first day had an increasing trend with higher concentrations recorded on the order of 470 ppb. However, on the next day, the concentrations fell to 7.9 ppb at the start of the day. Therefore, a definitive peak could not be identified for this location, although the rate of concentration increase was slowing down on day 1. For study days 2 and 3, the concentrations were mostly the same order of magnitude, around 10–15 ppb. For study days 4 and 5, the concentrations decreased to the 3–7 ppb range. On day 5, the last day of the study, SF_6 concentrations were on the order of 3 ppb.

3.2.6 Bleeder Shaft—Figure 12 shows sampling data from the surface site at the bleeder shaft. The gas samples were taken at the top of the bleeder shaft located at the back of the panel. The tubing inlet was approximately 10 ft below the shaft collar. The arrival and peak of SF_6 at the surface site occurred on day 1. The gas arrived approximately 4 h after the release of SF_6, and the peak concentration was observed approximately 7 h after the release. Decreasing concentrations were measured from this site for days 2, 3, 4, and 5 with an average concentration of approximately 2 ppb. As with the bleeder locations, a tail end zero

concentration was not observed at this location. The measurements at this location and the bleeder locations confirm that a portion of the tracer gas stayed within the gob, as was indicated from both sampling locations in the bleeders.

4 Summary and Conclusions

Sufficient ventilation air on a longwall face is critical for safety and health of crews working in the face area and to meet statutory requirements for gas concentrations. A face test indicates pathways of ventilation air movement. Although the data from this study at a trona mine in Wyoming show air movement from the headgate towards the tailgate, this movement occurs in the main face airflow within the shield legs. With the first arrival of the tracer gas released into the legs of shield 1 found at the mid-face location, transport occurred either in the shield legs or the active panel gob. Transport from the release point at the first shield to the mid-face line 3 was also noted, although the configuration of the pathway is not well defined.

Monitoring on the active face also shows that SF_6 persisted on the longwall face for more than 2 h following the release into the legs of shield 1, which may indicate residence time within a portion of the gob. Also, there was a late and intermittent show of SF_6 on line 1, suggesting that the primary movement was not in the face air, and that some degree of exchange with the gob occurred near this portion of the face. At line 2 on the face, no tracer gas was observed throughout the duration of the face test. This outcome can be inferred due to the presence of the zero entry in the headgate. The zero entry was located between lines 1 and 2, and it became part of the gob as the face retreated. Approximately 65% of the intake air came through the zero entry. This influx of intake air towards the tailgate might have diluted the tracer gas at line 2 beyond detectable limits or may have pushed the tracer gas back into the gob. Movement of the tracer gas to the inby tailgate location at line 6 was indicated either as transport in the main face airflow or the presence of another path of movement, possibly in the front of the gob.

The gob tracer gas test indicated a rapid path of movement of gas from two breaks inby the face on the headgate side of the gob to the sampling location just outby the tailgate corner on the active face. The primary path of tracer gas movement from this release location was towards the back of the panel at a velocity of about 0.19 m/s (37 fpm). Transport of tracer gas through the gob was rapid to the headgate and tailgate bleeders and to the bleeder shaft near the back of the study panel. The maximum concentration of tracer gas at all three locations was reached on the first day of testing. Low concentrations of tracer gas were measured at all three of these locations throughout the remainder of monitoring. The presence of multiple pathways of face air movement and the range of pathways of gas transport and rates of movement demonstrated by this and related NIOSH field studies show a degree of interaction between the gas at the front of the active panel gob and the face air; therefore, atmospheric monitoring in this area can greatly improve mine safety.

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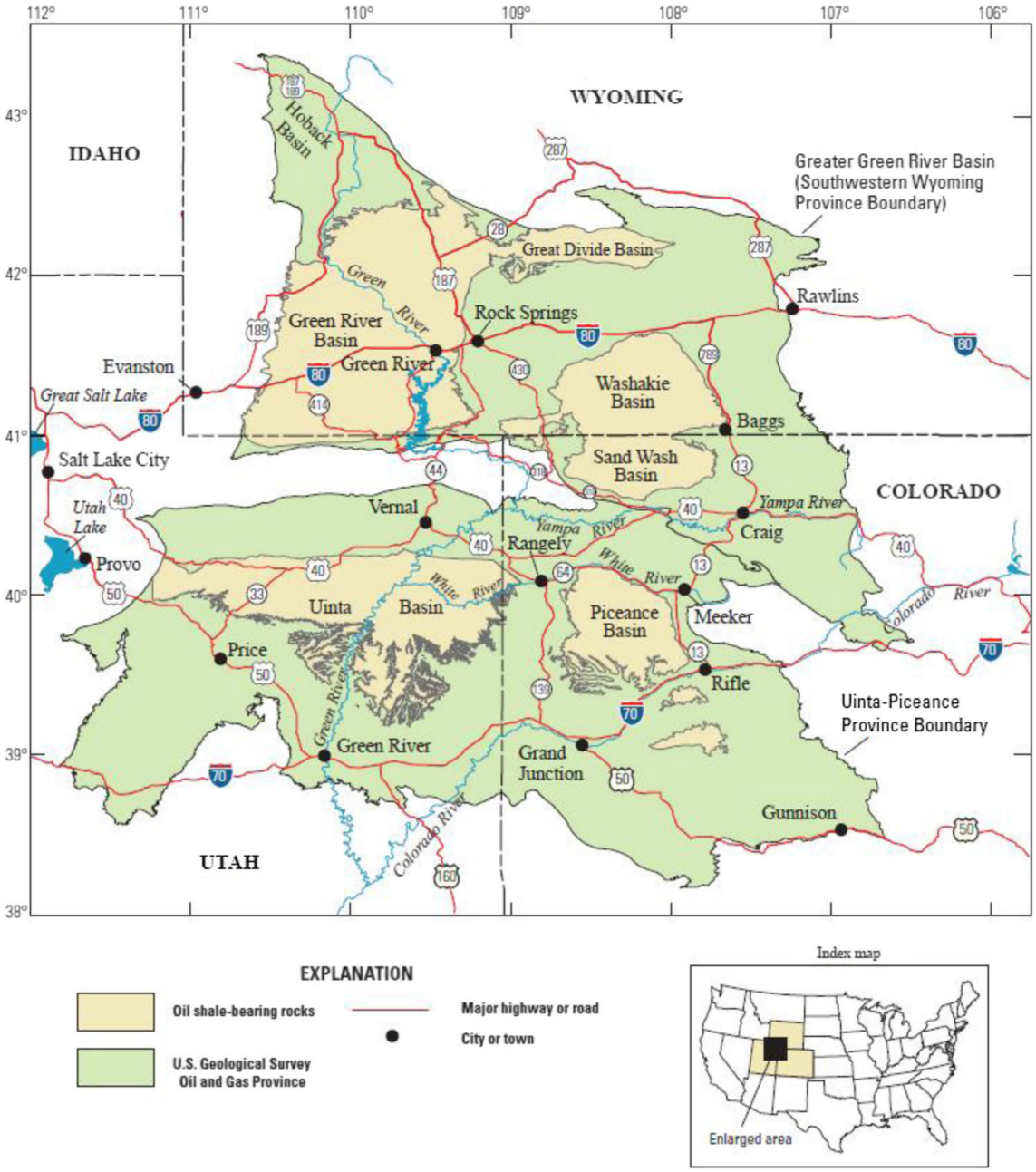

Fig. 1.

Green River Basin and associated major sedimentary basins in Wyoming, Utah, and Colorado, USA [20]

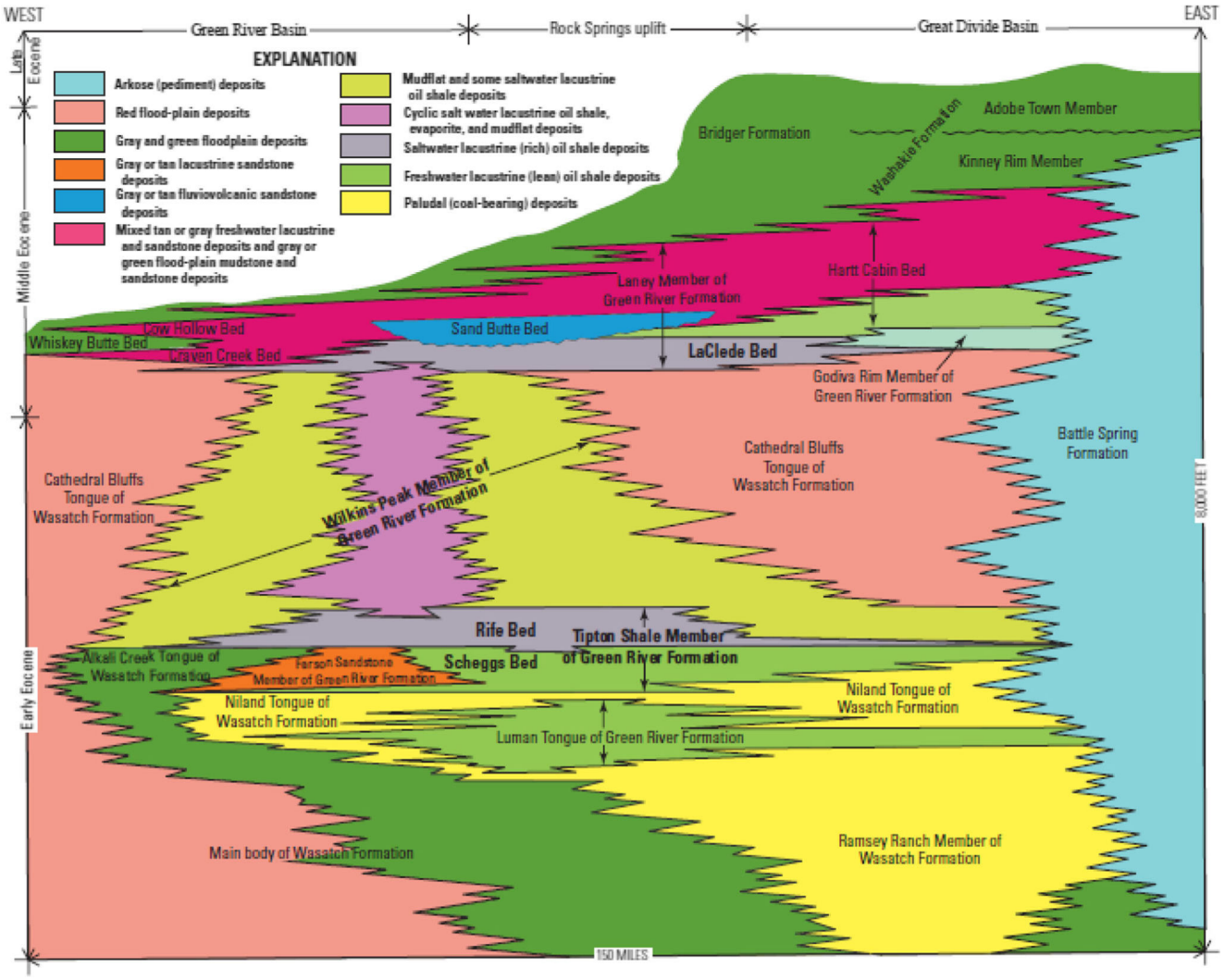

Fig. 2.

Eocene stratigraphy of the Green River Basin, Wyoming, USA. Trona beds of economic importance are contained within the Wilkins Peak Member, Green River Formation [20]

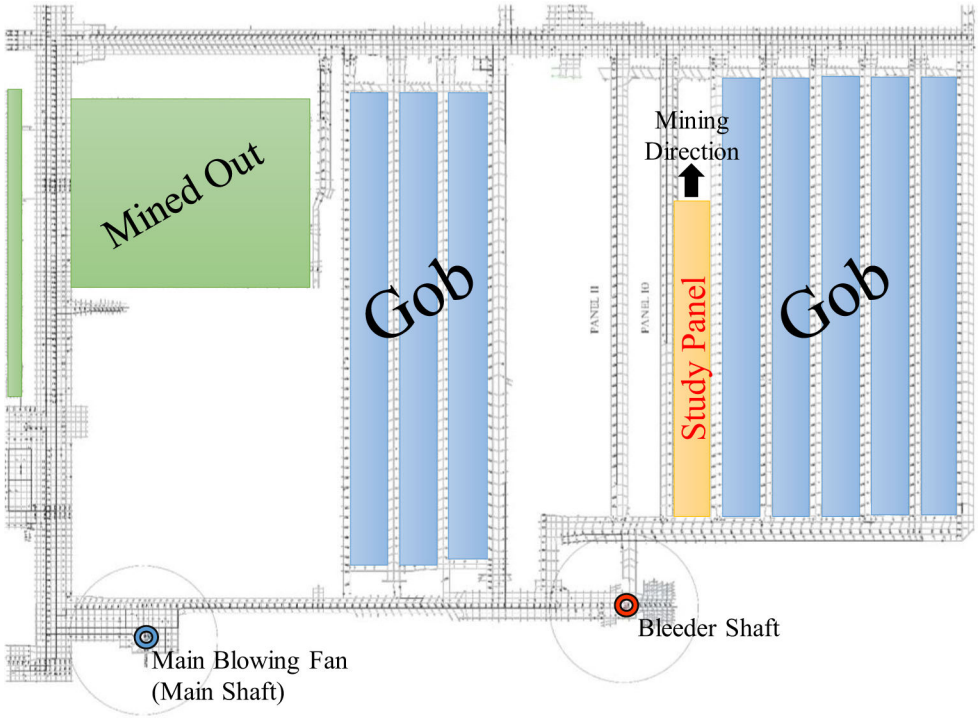

Fig. 3.
Mine study site showing the study panel and previously mined-out areas

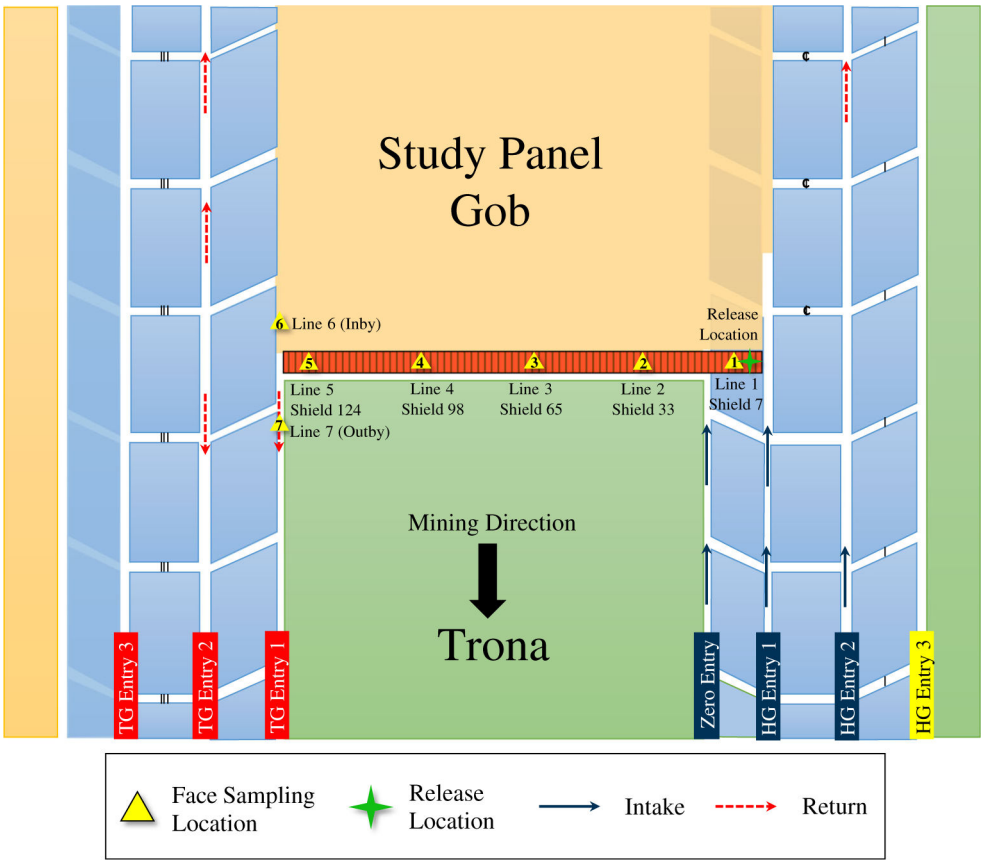

Fig. 4.

Schematic showing the mine ventilation configuration and monitoring locations for the face test

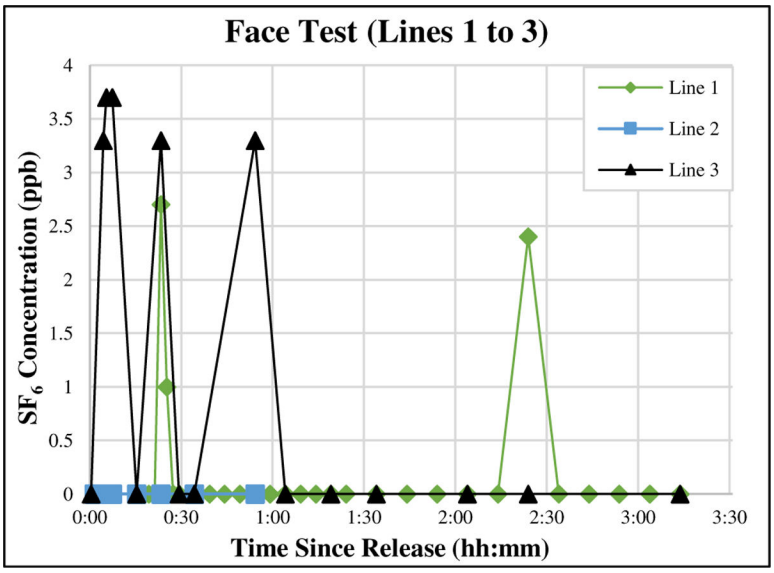

Fig. 5.

Tracer gas concentrations for lines 1 to 3. The first arrival and peak occurred on line 3, prior to the arrival and peak on line 1

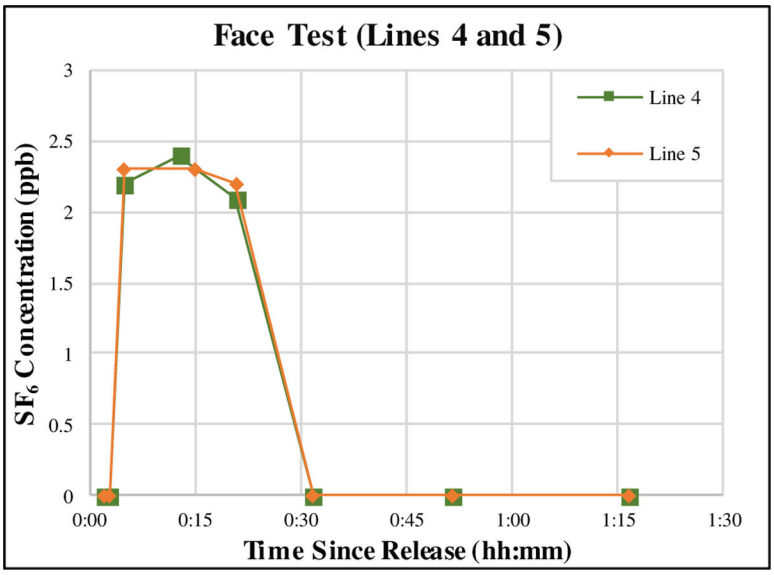

Fig. 6.

Tracer gas concentrations for lines 4 and 5. The arrival occurred at approximately the same time

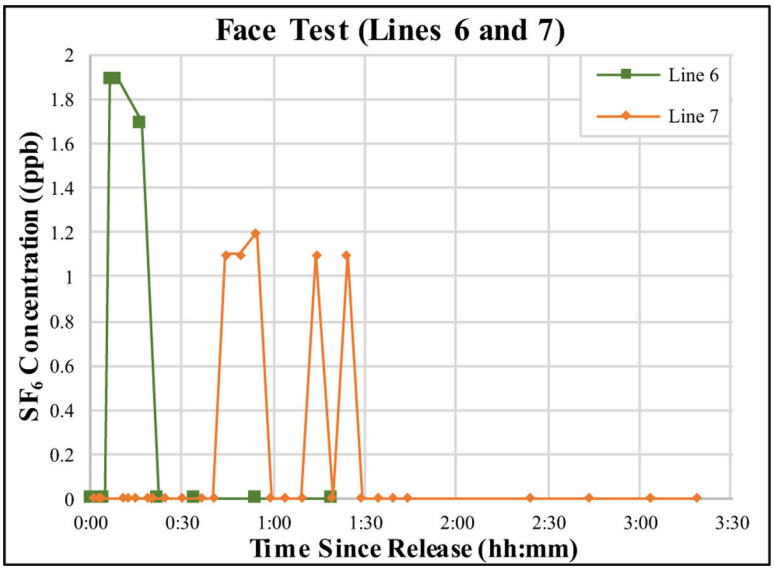

Fig. 7.

Tracer gas concentrations for lines 6 and 7. The arrival occurred on line 6 located inby the face prior to arrival on line 7 located outby the face. Line 6 peaked before line 7

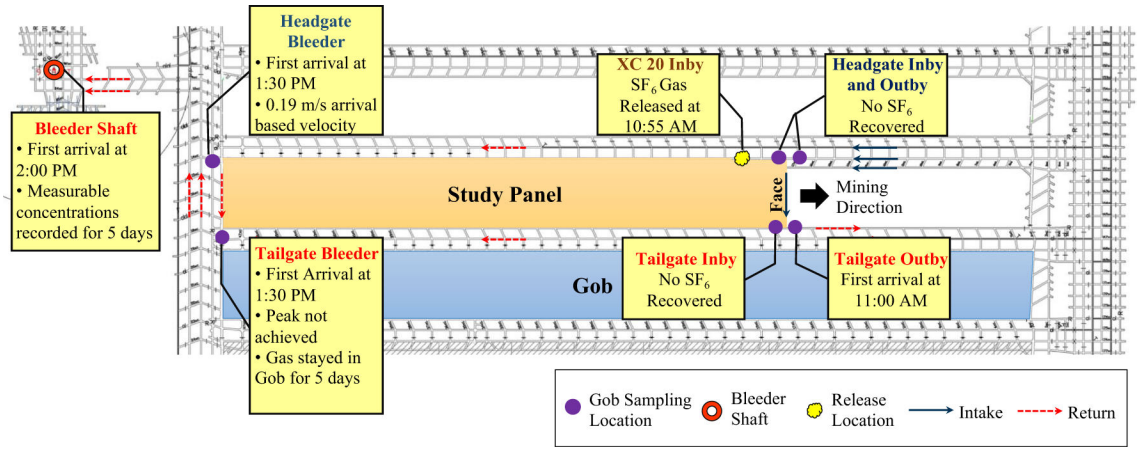

Fig. 8.

Schematic showing gob test sampling locations and results

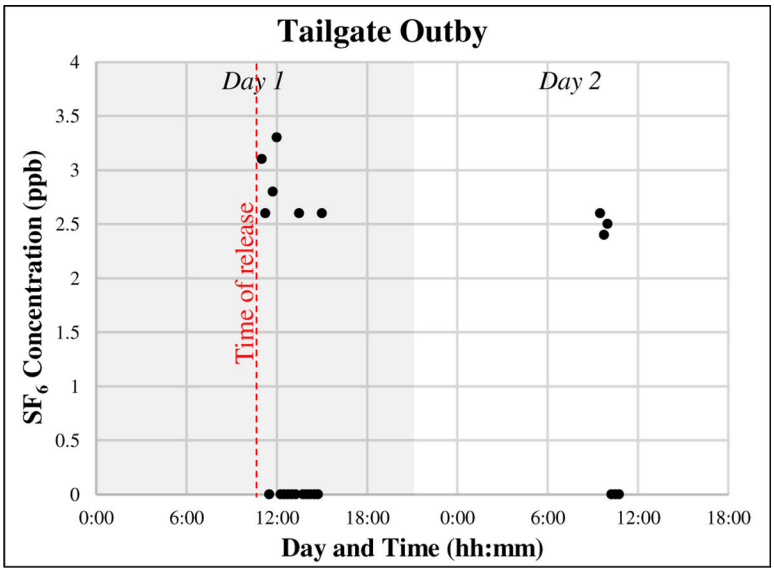

Fig. 9.
Tracer gas concentrations from tailgate outby sampling location

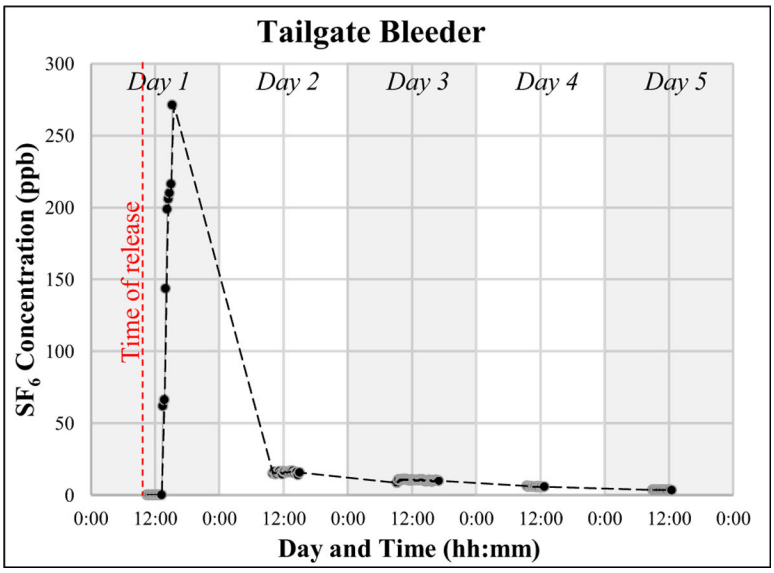

Fig. 10.
Tracer gas concentrations from tailgate bleeder location

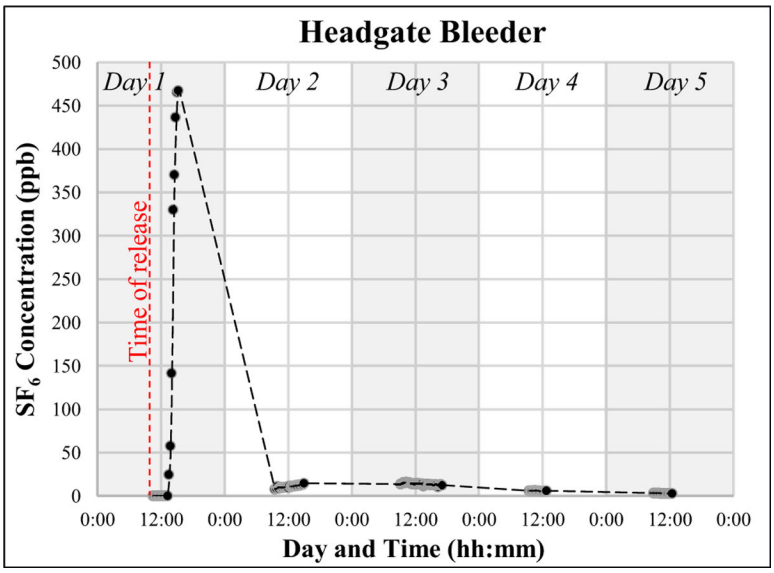

Fig. 11.
Tracer gas concentrations from headgate bleeder location

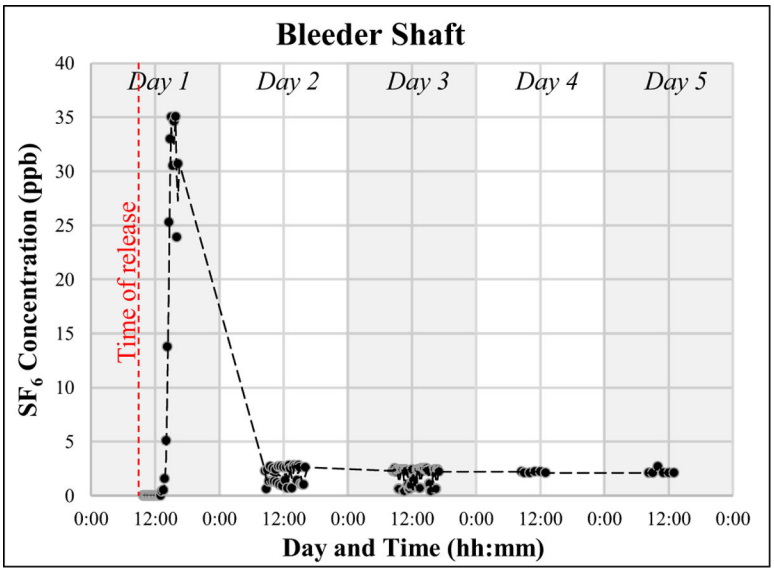

Fig. 12.
Tracer gas concentrations from bleeder shaft location

Table 1

Transit Times

Location	Length (m)	Pump rate (L/min)	Volume (L)	Transit time (minutes)
Line 1, shield 7	152	5.00	13	3
Line 2, shield 33	152	5.00	13	3
Line 3, shield 65	152	5.00	26	3
Line 4, shield 98	305	5.00	26	5
Line 5. shield 124	305	5.00	26	5
Line 6, inby	152	5.00	13	3
Line 7, outby	152	5.00	13	3

Table 2

Flow Rates

Location	Velocity (m/s)	Area (m^2)	Flowrate (m^3/s)	Flowrate (kcfm)
Line 1, shield 7	1.29	15.0	19.3	40.8
Zero entry	2.73	12.3	33.5	71.0
Line 2, shield 33	2.97	15.7	46.7	98.8
Line 3, shield 65	3.30	13.9	45.9	97.3
Line 4, shield 98	4.31	13.1	56.4	119.5
Line 5, shield 124	3.41	17.8	60.7	128.7
Line 6, inby	5.84	9.5	55.3	117.3
Line 7, outby	1.29	9.5	12.2	25.9